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Investigations of Transient Sediment Dynamics by the DSLP®-Method

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Summary

Within the framework of the PROMORPH project, measurements of highly-dynamic sediment processes were performed with the aid of DSLP('Detection of Sediment Layers and Properties')-technology in the benthic boundary layer of the PROMORPH investigation area. The aim of these measurements was to obtain in-situ data for assessing the applicability of various models for simulating near-bottom sediment transport. DSLP - technology has proven its ability to resolve near-bottom sediment transport phenomena convincingly. Exemplary results are presented to illustrate the practical application of the DSLP-method.

Zusammenfassung

Im Rahmen des PROMORPH-Projektes wurden mittels der DSLP-Technologie ('Detection of Sediment Layers and Properties') Messungen zu den hochdynamischen sedimentologischen Prozessen in der benthischen Grenzschicht innerhalb des Untersuchungsgebietes durchgeführt. Ziel dieser Messungen war es, in-situ Messdaten zu bekommen, um die Anwendbarkeit verschiedener Modelle zum bodennahen Sedimenttransport bewerten zu können. Die DSLP-Technologie hat ihre Fähigkeit, bodennahe Sedimenttransportvorgänge aufzulösen, überzeugend nachgewiesen. Beispielhafte Ergebnisse werden hier dargestellt.

Keywords

DSLP-technology; echo-sounder; acoustic classification; fluid-solid interface; near-bottom sediment transport; suspension concentration; bathymetric changes; PROMORPH

Contents

1. Introduction

Investigations concerned with the dynamics of sedimentological processes are characterized by a large variety of requirements. In particular, information on the dynamics of sedimentological processes is of great importance for effective dredging management, port maintenance and development, waterways management, and coastal and flood protection systems. Information on the origins, whereabouts and quantities of transported sediment as well as the temporal variation of these processes is essential in this context. This places high demands on the temporal resolving power of the methods used to acquire this information. By means of the DSLP-method it is now possible to fulfil these high requirements. The implementation of DSLP-technology in different measuring techniques, combined where necessary with concomitant flow measurements, leads to hitherto unattainable high-quality remote sensing data on the dynamics of sedimentological processes.

These special features of the DSLP-method were required for the purpose of data acquisition within the framework of the PROMORPH project. This paper describes the DSLP-measuring technology and also presents exemplary results which demonstrate the application of the method for investigating highly instationary sediment dynamics. A detailed analysis of the scientific results of the measurement campaigns using the DSLP-method is presented by SCHROTTKE and ABEGG (in this volume).

2. Measurements based on DSLP-Technology

2.1 DSLP-Technology for Investigating Sediment Dynamics

The DSLP-method ('Detection of Sediment Layers and Properties') developed by General Acoustics GmbH (EDEN et al. 2000, 2001; SEEFELDT et al. 1999) is an innovative hydro-acoustic method for measuring the properties of suspended and near-bed sediment layers. The underlying technology of the DSLP-method is essentially different to that implemented in commonly-used echo sounders such as single or multi-frequency two or three-dimensional echo sounders or sediment echo sounders. The fundamental difference between this method and other echo sounding systems is that the DSLP-system operates independently of the utilized acoustic frequencies, thereby permitting an unambiguous and definite high-resolution physical analysis of the acoustical interaction between sound waves and targets (e.g. suspended matter and sediment types). This permits the detection of suspensions with a wide range of concentrations (e.g. fluid mud, suspended sediments, sand suspensions, etc.) and a wide range of thicknesses (3 cm up to several metres). The physically-proven accuracy of detecting interfaces such as e.g. the fluid-solid interface between suspensions and consolidated sediments is of the order of 3 cm. An estimation of the depth of these interfaces is always independent of the results of other measurements and/or calibrations. In contrast to conventional echo sounding systems, which operate with a measurement accuracy of no less than a decimetre, the DSLP-method thus permits high-accuracy detection of near-bottom sediment suspensions as well as high-precision determination of layer thicknesses and concentration-related parameters. This capability of the DSLP-method adds to the importance of remote sensing of near-bottom sediment and suspension dynamics.

Two main features of the DSLP-method are utilised in particular. The first feature is the ability to detect the fluid-solid interface with high definition owing to the first significant appearance of acoustic reflection over the full applied wave band. Technically, this could be achieved by high-resolution complex signal analysis of the received acoustic waves. The transmitted acoustic pulses are affected by scattering, reflection and damping (frequency-dependent and frequency-nondependent processes), thus providing an unambiguous representation of material structure and stratification. In the present case the adopted wave band ranges from 12.5 to 200 kHz and the signal analysis for detecting the fluid-solid interface is bounded by an aperture angle of 3 degrees. Bathymetric variations over the bottom area exposed to sonic waves are neglected. The resulting depth value is then set to its highest value within this area, which is an admission requirement for navigation echo sounders.

The second feature used is the ability to differentiate between various types of scattering. Often a correlation between backscatter strength and suspension concentration is applied, as determined from probe samples. It is well-known that (mostly linear) interpolation between discrete values is questionable due to the unknown basic acoustic scattering processes which govern the measured value of backscatter strength. The complex signal analysis of the multi-frequency acoustic signal in the DSLP-method results in a differentiation of the various type of scattering processes such as single and multiple scattering or diffusive scattering. These distinct processes are classified according to so-called "nonlinear damping parameters". In the DSLP-method a detected suspension or sediment layer is thus classified not only by the (depth-corrected) backscatter strength but also by a set of nonlinear damping parameters. The latter is referred to as acoustic classification. Temporal and/or local changes in the values of this parameter set (not essentially a change in backscatter strength) represent a structural change in sediment/suspension stratification. On account of this outstanding feature, combined with high depth-resolution, the DSLP-method is extremely suitable for measuring highly concentrated near-bottom suspension layers (MÜLLER et al., 2001).

2.2 Measurements

Having confirmed the capabilities of the DSLP-method (EDEN et al., 1998; LIEBETRUTH, 2004) for measuring highly instationary sediment dynamics, a measuring strategy aimed at gaining a deeper insight into local (point and cross-sectional) sediment dynamics over a tidal cycle was developed in cooperation with the Research and Technology Center Westcoast (FTZ) in Büsum (SCHROTTKE and ABEGG, in this volume). The high depth-resolving capability of the DSLP-method, combined with a sampling frequency of up to 10 Hz, permits high-resolution measurements of local sediment dynamics processes.

The DSLP-measurements were carried out within the framework of the measuring campaigns undertaken by the FTZ Büsum. The technical equipment of the complete DSLP-system was adapted to the available infrastructure on board the research vessel "Südfall". A high-precision DGPS with an outboard reference station was included in the DSLP-system to fulfil the requirements of accuracy (horizontal local resolution of 1 cm, height resolution of 1 cm with an accuracy of 2 cm). The accuracy of the DGPS-system was also sufficient to compensate for heave.

Two different measuring schemes were implemented. Firstly, high-frequency (5 Hz) point measurements were made to investigate high-frequency sediment dynamics at a local position. Secondly, continuous measurements in a cross-section were made over a tidal cycle in order to resolve the tidal dependence of near-bottom sediment dynamics. The request on the positioning accuracy at both measuring schemes is extremely different. DGPS together with a good seamanship were responsible for the fact that the measurements over a cross-section were almost perfect. But these prerequisites are not sufficient for performing point measurements. Although motion compensation methods were used, a sufficient local stability due to movements of the moored vessel (Fig. 1) could not be reached. Thus, the measured depth

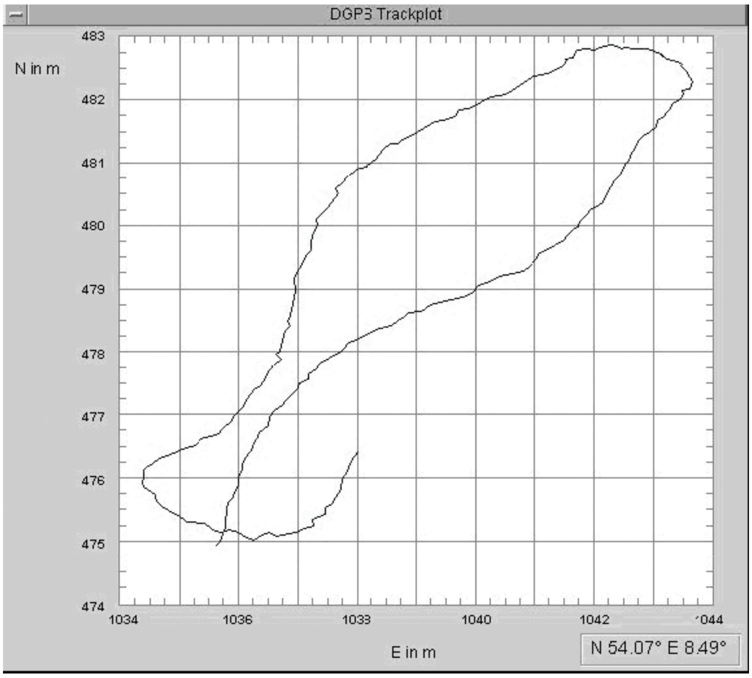


Fig. 1: Example of a local measurement; duration: 240 sec, mean flow velocity: 20 cm/s; local stability could only be attained over an area of 10 × 10 metres; the figure was obtained by running DSLP-software during measurements

levels of the various suspension layers are mostly found to be a non-resolvable combination of small bathymetric changes (cf. a depth accuracy of 3 cm) and instationary changes in the thickness of these suspension layers.

3. Results and Evaluation

3.1 Point Measurements

In all DSLP-measurements (during 6 measuring periods at run time and at all measurement locations) the same basic qualitative suspension/sediment characteristics were detected. Generally speaking, two distinct near-bottom suspension layers were identified. The overall thickness of these two high-concentration suspension layers was found to be small, i.e. mostly of the order of 10 centimetres (dynamic rise of up to 40 cm). Above these two layers, an additional suspension layer was detected. According to the afore-mentioned acoustic classification (linear scattering), it is deduced that the sediment concentration within this layer is extremely low. The fluid-solid interface borders the bottom suspension layer abruptly with increasing depth (Fig. 2). Although dynamic changes in the local depth of this interface were detected, it was not possible to draw a clear distinction between highly transient sediment/suspension dynamics and small bathymetric changes due to the inability to differentiate between the local instability of the research vessel and bathymetric variations within an area of 10 × 10 metres. A necessary prerequisite for such investigations, i.e. high depth-resolution and accuracy, is given by the DSLP-system. These investigations thus underline the need for a fixed mounting to differentiate between the latter two effects.

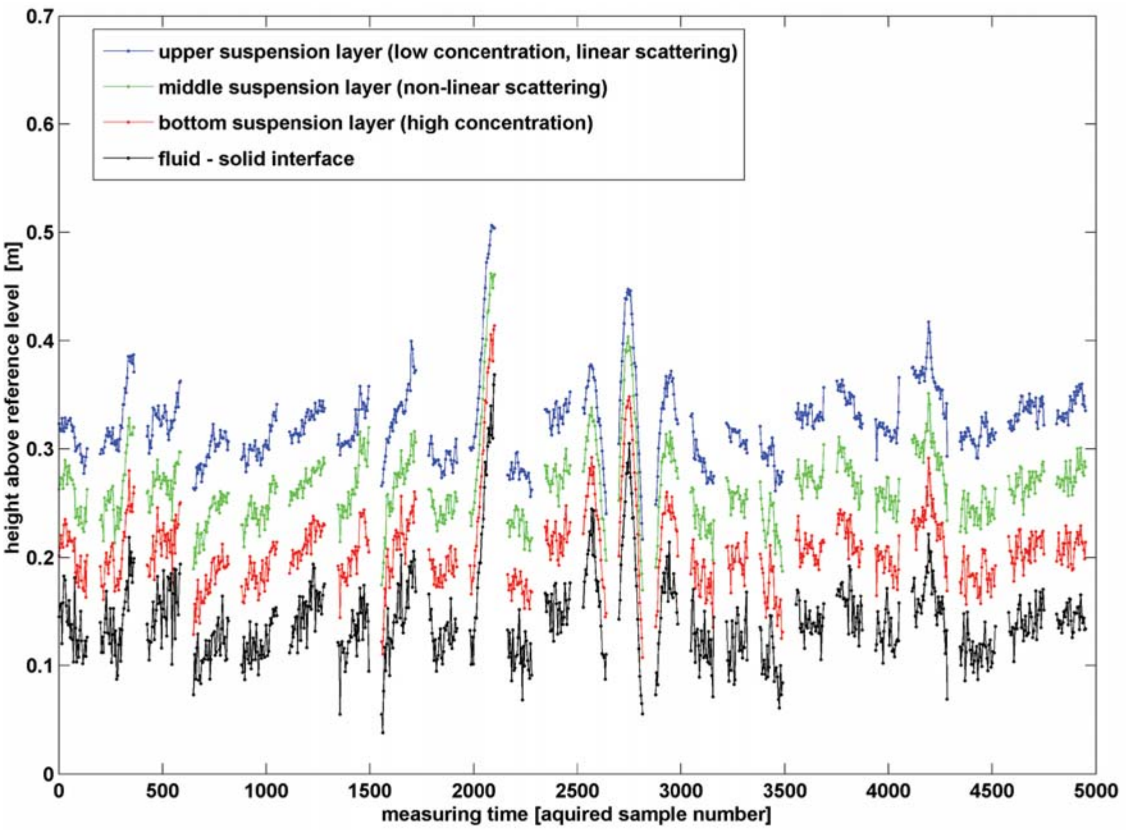
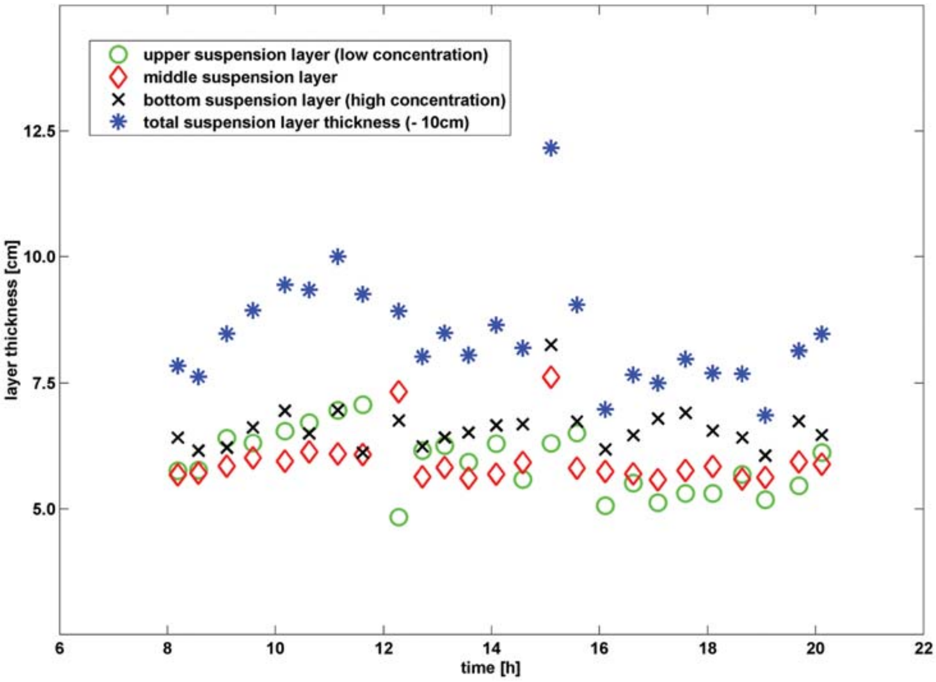


Fig. 2: Typical results of local DSLP-measurements; 1-second mean values of 5 Hz measurements, 25 measuring cycles (30 s) uniformly distributed over a full tidal cycle at a single location; the reference depth is taken to be the lowest single value of the fluid-solid interface ever measured at this location

The overall thickness of both high-concentration suspension layers is small, mostly in the range of 10 centimetres (dynamic rise of up to 40 cm). Acoustically, these suspension layers are classified by a set of nonlinear damping parameters. These are numerical parameters that describe typical signal characteristics dependent on the different (nonlinear) sound-matter interactions found in the complex multi-frequency acoustic signal. In the present case an individual characteristic acoustic parameter of this type was found for every suspension layer. A variation of the value of this parameter is typical for a change in the layer concentration (increasing nonlinear damping implies increasing concentration). The significance of the presence of a parameter of this subset is typical for a special inner structure of this layer. Due to the mainly simple inner structure of the detected suspension layers in this case, they are described by only one parameter. A correlation between the significance of parameters derived from the subset and their assigned values to an inner structure of matter or a specific concentration can only be realised by an accompanying analysis of probe samples taken at the same location and time.



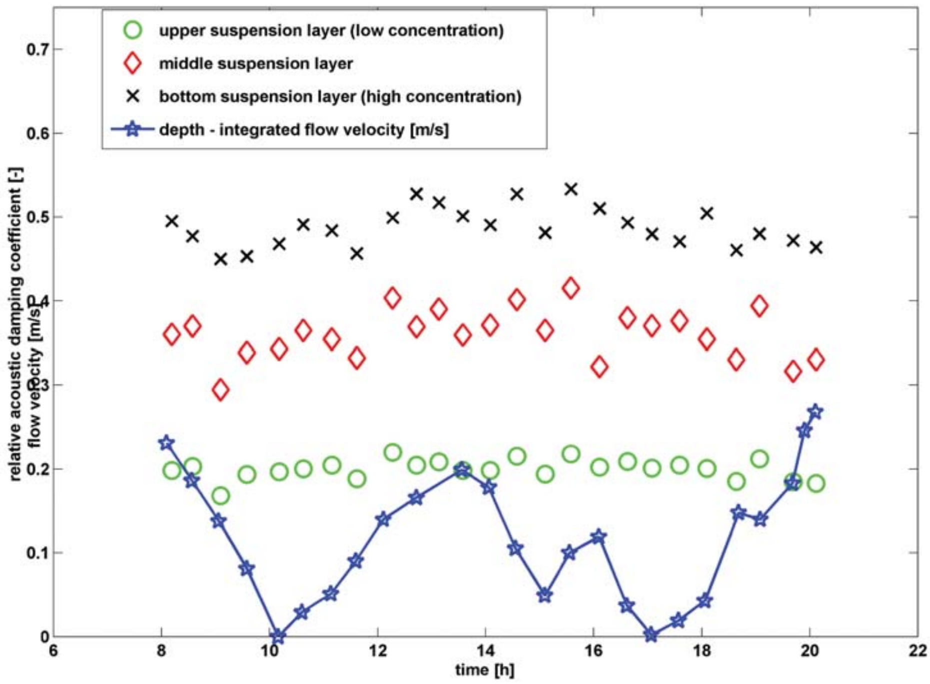


Fig. 3: Thickness of the detected suspension layers (upper figure) and values of the layer-specific acoustic parameter (lower figure) in relation to the time dependence of the mean flow velocity; the values of each single acoustic parameter describe the concentration variations within the represented layer. However, the relationship between values in different layers on a specific date cannot be linearly transferred to obtain a relationship between suspension concentrations

At all measuring locations the suspension layers are described by the value of the layer-significant acoustic parameter and the thickness of this layer. An interface between the suspension layers may either be characterised by an abrupt change in concentration (density jump) or an abrupt change in the inner structure, which is not necessarily accompanied by a density change. The interfaces between layers are always recognised in this case as interfaces between slightly different inner structures. Variations in the specific layer-significant parameter over the measured tide as well as variations in the thickness of the detected layers are small (Fig. 3), but not negligible. The qualitative layer dynamics are comparable to the results of other surveys (EDEN et al., 1998). An estimate of the concentration profile within a layer is not possible. This is due to the depth accuracy of 3 cm associated with the DSLP-system and a mean thickness of 6–7 centimetres for each identified layer. Owing to the fact that a systematic collection of probe samples with a depth resolution of 3–6 centimetres within the near-bottom suspension layers could not be performed by means of the sampling technique available, it was not possible to correlate the DSLP-results with probe samples.

3.2 Measurements in a Cross-Section

In contrast to the above-mentioned investigations of short-term sediment dynamics processes (Section 3.1), emphasis is now placed on the high-resolution measurement of suspension/sediment dynamics in a cross-section over a full tidal cycle (Fig. 4). By means of the DSLP-method it is not only possible to determine the depth positions of the individual suspension interfaces, but also to resolve the concentration classes of the suspension layers. Thus, it is also possible to determine a balance between the suspension and bed load.

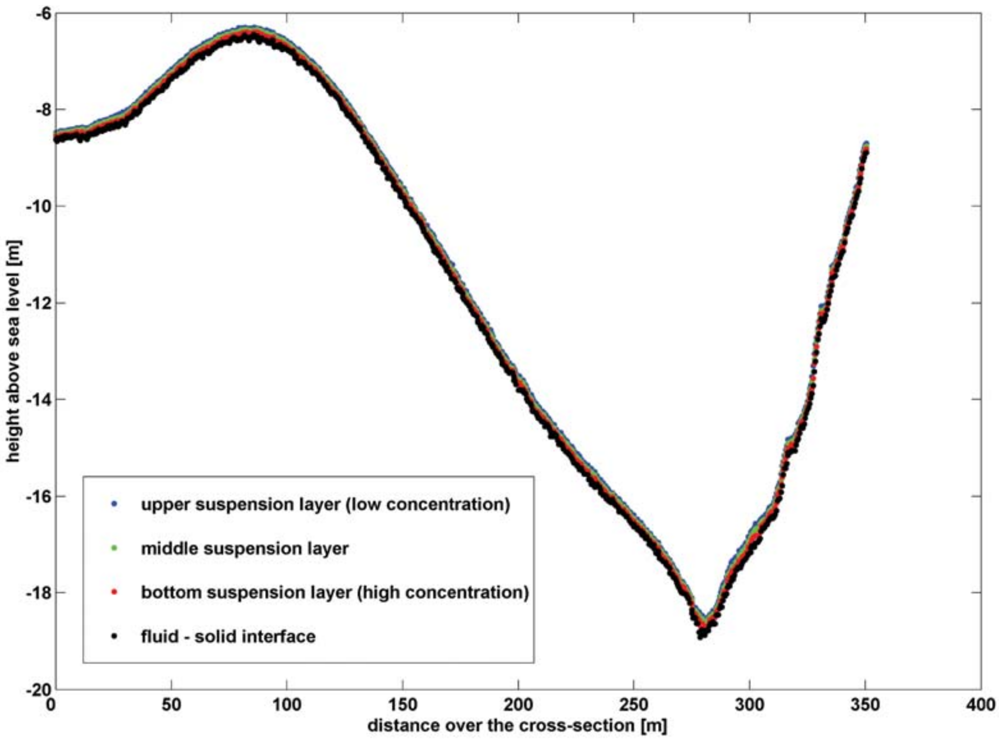


Fig. 4: Typical results of cross-sectional DSLP-measurements which resolve a) the interface between "clear" water and a low-concentration upper suspension layer, b) the interface between this upper layer and the first high-concentration suspension layer, c) the interface between the two high-concentration suspension layers and d) the fluid-solid interface (interface between the bottom suspension layer and the first layer of consolidated sediment exhibiting the property of solid matter)

The temporal development of the layer thickness of the characteristic suspension layers detected in a 350m-wide cross-section (Fig. 4) over a period of 12 hours is presented in Fig. 5. In combination with concomitant level and/or flow measurements, it seems possible to assign the layer dynamics to e.g. fluid dynamic events. Regions as well as periods of higher layer dynamics are easily recognisable. During the measuring period only weak sediment and suspension dynamics was observed. The overall thickness of the near-bottom high-concentrated suspension layers is smaller than 3 dm. Temporal variations of the layer thicknesses are distinct at the deepest part of the cross-section and especially for the bottom suspension layer. The results give not an indication of a significant vertical (turbulent) transport at the depth range up to 3 dm above bottom, which would lead to a significant change of thickness of these layers. If there exist any near bottom transport and which amount of suspension at the depth range up to 3 dm above bottom will be transported can not be concluded directly from these measurements. Therefore a combination with flow measurements and/or simulation results as well as with measurements of local suspension concentration with a desired depth resolution better than 1 dm are necessary.

Combination of the DSLP-results, which were ordered by the Research and Technology Center Westcoast (FTZ), with other results as well as further discussion is presented by SCHROTTKE and ABEGG (in this volume).

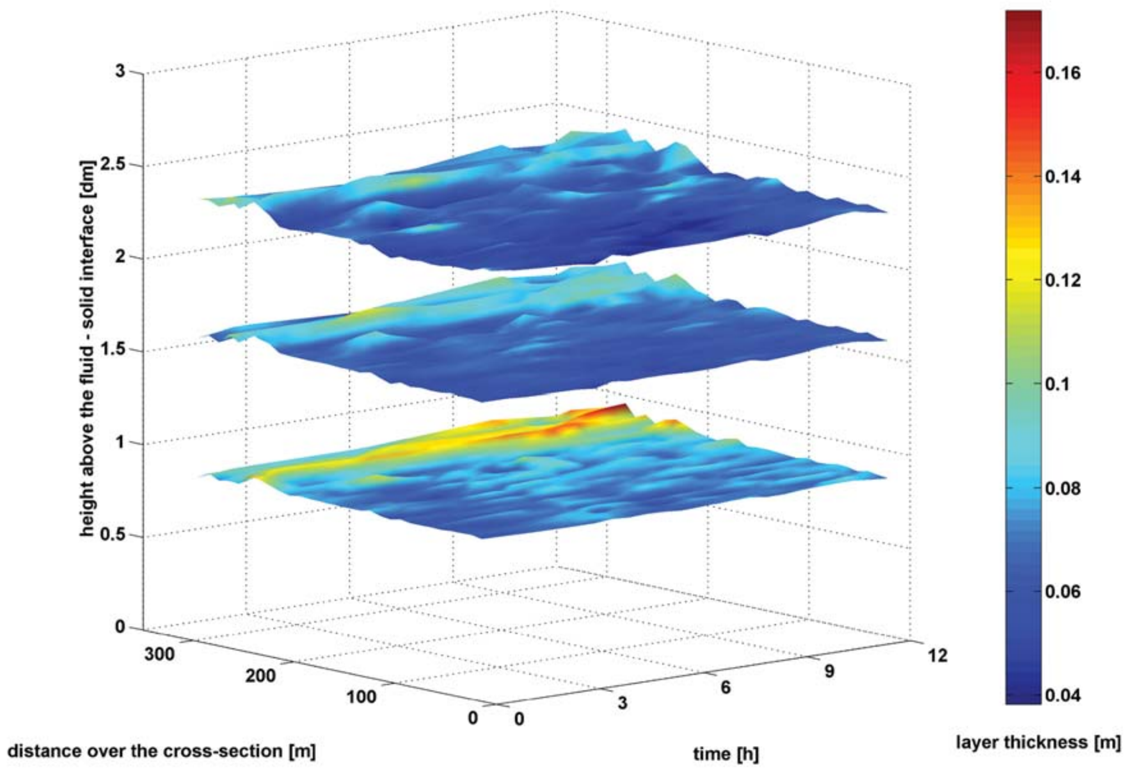


Fig. 5: Results of DSLP-measurements in the 350 m wide cross-section of Fig. 4; three different suspension layers were detected which could be distinguished by their acoustic behaviour; the mean concentration of the distinct layers is almost constant; here the selected representation of the results is an extension of the representation of local results like presented at Fig. 3 to the 3rd dimension – the distance over the cross-section

4. Conclusions

The DSLP-method is the first "echo sounder" method that permits the measurement of sediment dynamics processes over time intervals varying from seconds to days, and from weeks to months. This capability is based on the high depth-accuracy performance of the DSLP-method combined with the ability to differentiate between and uniquely classify physically classifiable sediment and suspension layers acoustically. On account of the implemented measurement technology and application characteristics of the DSLP-method it is possible to resolve sediment dynamics processes according to requirements. The information content of DSLP-measurements may be enhanced by the inclusion of accompanying measurements such as e.g. flow measurements. As confirmed by the present investigation, the DSLP-method offers new possibilities for measuring the dynamics of sedimentological processes.

5. References

EDEN, H.; VORRATH, D. and MÜLLER, V.: Erfassung von Sedimenten geringer Dichte. Final Report of the KFKI project 616-84020-MTK-0607, Kiel, 1998.

EDEN, H.; MÜLLER, V. and VORRATH, D.: DSLP® – an innovative echo sounding technology. Hansa, 137 (2000) 10, pp. 36–39, 2000.

EDEN, H.; MÜLLER, V. and VORRATH, D.: Exact Detection of Suspension, Sediment Layers: New Technology. Sea Technology, 42 (2001) 10, pp. 31–36, 2001.

EDEN, H. and MÜLLER, V.: High Resolution Detection of near Bottom Sediment Dynamics – a Challenge to acoustic remote sensing Techniques. Proceedings in HYDRO 2002 "Sounding the Future", Deutsche Hydrographische Gesellschaft e.V. (Herausgeber), Kiel, 2002.

LIEBETRUTH, F.: Ermittlung der nautischen Sohle der Ems von km 47,3 bis km 48,1, Stellungnahme zu den geotechnischen, rheologischen und Echolot-Vergleichsuntersuchungen vom 8. bis 10. September 2003. Bundesanstalt für Wasserbau – Außenstelle Küste, Hamburg, 2004.

MÜLLER, V.; EDEN, H. and VORRATH, D.: Remote Sensing of Near-Bottom Sediment Dynamics by combined DSLP®- and LOG_aFlow®-Technology. XXIX IAHR Congress (Beijing), Beijing, 2001.

SCHROTTKE, K. and ABEGG, F.: Near bed suspended sediment dynamics in a tidal channel of the German Wadden Sea. Die Küste, Heft 69, 2005.